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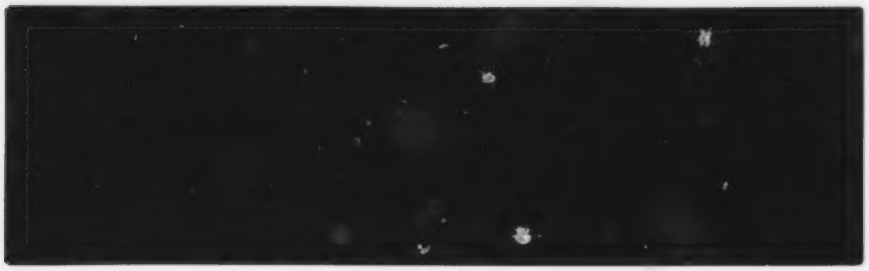

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A SIMULATION ANALYSIS MODEL FOR DRAGLINE OPERATION USING SLAM II

J.K. Szymanski and W.M. Borysuk

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A SIMULATION ANALYSIS MODEL FOR DRAGLINE OPERATION USING SLAM II

by

J.K.Szymanski* and W. M. Borysuk**

ABSTRACT

A cooperative effort in 1988 produced a SLAM II simulation model capable of realistically predicting operation performance of the dragline at Obed Mountain Coal mine. In order to model this stochastic system, the selection and estimation of probability distributions for a dragline cycle components is of paramount importance. Data was collected from the mine through time studies and analysis of production records. The available sample data was hypothesized using the deviations of sample cumulative frequencies of the cycle components from their theoretical values when tested by the stabilized probability plot method. The results showed that the simple Weibull or simple Lognormal were equally good candidates. Validation against production data from the operating mine showed that the model satisfactorily described the system.

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MODELE DE SIMULATION SLAM II POUR L'ANALYSE DU FONCTIONNEMENT D'UNE DRAGLINE

par

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RÉSUMÉ

Dans le cadre d'un travail coopératif mené en 1988, on a mis au point un modèle de simulation, SLAM II, qui permet de prévoir de façon réaliste le rendement de la dragline installée dans la mine de charbon d'Obed Mountain. Pour modéliser ce système stochastique, il est essentiel de pouvoir choisir et estimer les distributions de probabilité pour les composants du cycle de fonctionnement de la dragline. Les données ont été recueillies par le biais d'études par chronométrage réalisées dans la mine et d'analyses de dossiers de production. On a étudié diverses hypothèses sur la distribution des données-échantillons en utilisant les écarts des fréquences cumulatives des composants du cycle par rapport aux valeurs théoriques obtenues lorsqu'elles avaient été testées par la méthode de la courbe de probabilité stabilisée. Les résultats ont montré que l'hypothèse de la distribution simple de Weibull et celle de la distribution lognormale simple étaient également bonnes. La validation à l'aide de données de production provenant de la mine en exploitation a montré que le modèle décrivait le système de façon satisfaisante.

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INTRODUCTION

A computer model had been developed to simulate the operation of the dragline in an open-pit mine. In this model, stochastic simulation is used to reflect the random variation in duration of all components of it's time cycle. To model these simulation inputs, during the period of January-February, 1988 data was collected from an operating mine under the operating and environmental conditions in which the dragline was used. In this model the problem of concern was to develop a planning tool to estimate the expected production from a given dragline.

APPROACH

The model to simulate the operation of the dragline is intended for application to actual situations. Therefore, it was best to develop the model on the basis of a real-life problem. An operating mine contemplating the introduction of this model was chosen as the object of the study.

The following approach was taken:

1. Collect operating time interval data on all cycle components for the dragline in operation at the mine. This includes collection of information from production reports (buckets to walk and walk times).
2. An analysis of collected data includes statistical analysis on the validity of the chosen sample distribution using deviations of sample cumulative frequencies of the cycle components from theoretical values.
3. Formulate a simulation model of the dragline in which the stochastic character of the network activities (cycle times) must be identified.
4. Validate of the model by comparing simulation results with production results obtained in actual operation.

COLLECTION OF DATA

This section deals with the collection and analysis of time data for subsequent use in the simulation model of dragline operation. The mine is located in the Alberta foothills. It contains two principle coal seams of lower tertiary age. There is an average overburden thickness of 20m covering the number two seam. An interburden layer of approximately 12.5m separates the lower number one seam from the upper seam. The mine uses a PAGE 757 walking dragline exclusively to remove burden from the coal. The dragline is equipped with a 57.4cu.m bucket and a 88.7m boom inclined at 0.576 radians (33 degrees) from the horizontal. (see Fig.l).

This study is based on removal of the interburden only. The interburden is removed using a simple side casting stripping method. A large amount of rehandle is necessary to create a 81 m bench (excluding a 6 m wide safety bench) in order to expose the underlying coal. The rehandle material is spoil from overburden removal along the same cut. A pit width of 50 m is exposed. During the field study period, dragline cycle times were recorded using a stop-watch. The recording person was stationed inside the dragline cabin. The field work included monitoring during !he day shift.

Four basic measurements were recorded prior each cycle:

- drag time,
- swing time,
- dump time,
- swing and reposition:ion time.

In addition to the basic time measurements the number of buckets and total time of walking per shift were recorded as simulation model control variables.

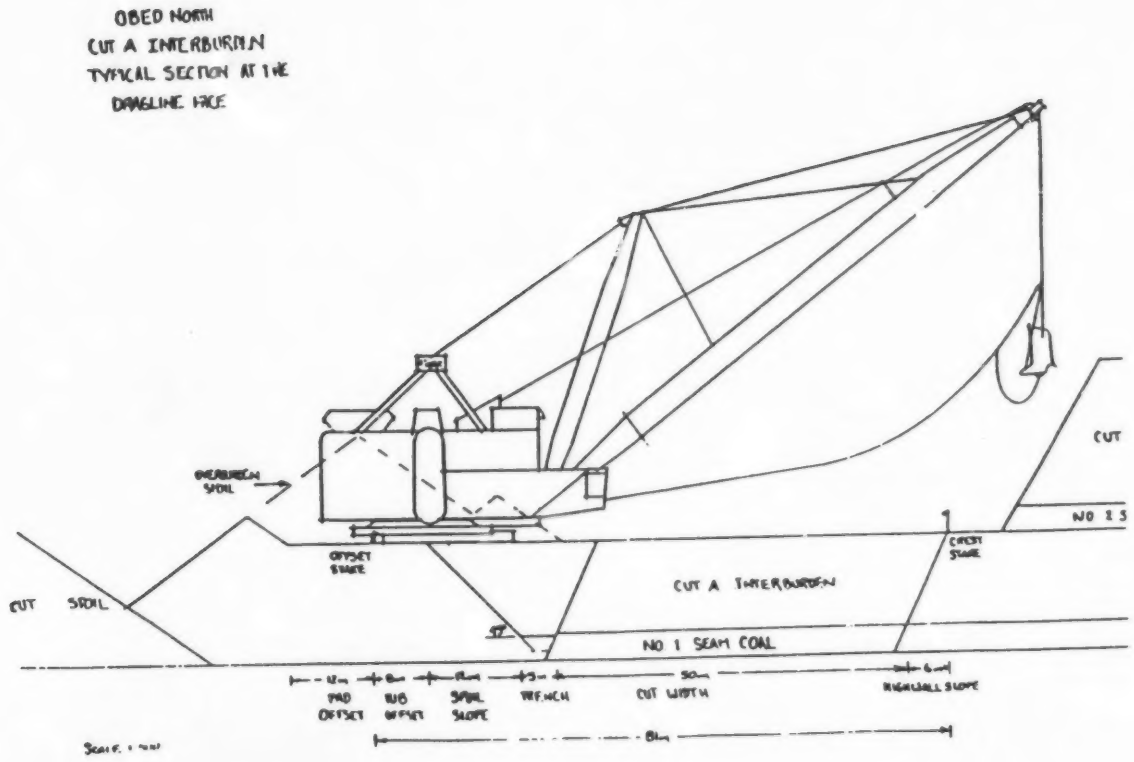

Fig. 1 Typical section at the dragline face.

STATISTICAL ANALYSIS OF COLLECTED DATA

The collected cycle data was tested by comparing the cumulative frequencies of sample data with various theoretical models. By plotting theoretical cumulative frequency versus observed frequency, one measured the departures from the 45° line on the plot as relative goodness of fit with respect to a particular distribution model. When the particular arcsine scaling of the stabilized probability plot procedure is used, the sample variance across the distributions are equalized and several distributional models can be visually and objectively compared for goodness of fit. The sample data was also fit to a distributional model by plotting the model against a histogram made from collected data frequencies. The results showed that the Lognormal or simple Weibull were good candidates.

A Lognormal cumulative distribution function (c.d.f.) may be defined mathematically as

$$F(t)= \begin{cases} 1/(t*\sigma*\mathrm{sqr}(2\pi))\ e^{-(\ln(t)-\mu)^2/(2\sigma)^2}, & t>0 \\ 0, & t<0 \end{cases}$$

Where:

F(t) - probability of a value less than or equal to t occurring,
t - cycle times,
u - $1/n\ \Sigma \ln t_i$,
σ – $\Sigma\ (\ln t_i - \mu)^2/n$,
e - - exponential

The parameters MU (μ) and sigma (σ) are related to the mean and the variance by the following relationship:

$$\text{mean} = e^{(\mu + \sigma 2/2)}$$

$$\text{variance} = e^{2\mu + \sigma^2}\ (e^{\sigma^2} - 1)$$

Estimation of the Lognormal distributions parameters from the time study data was done using the Newton-Raphson iteration technique. This technique uses maximum likelihood estimates to find the parameters. Table 1 shows the estimated Lognormal distribution parameters for all cycle components.

Table 1 Estimates of parameters of dragline cycle times from Lognormal distributions

CYCLE TIME COMPONENTS	DISTRIBUTION PARAMETERS		MEAN	STD.DEV
	SIGMA	MU	(MIN)	(MIN)
DRAG	0.3660	-1.3517	0.2767	0.1048
SWING	0.2727	-1.0812	0.3520	0.0978
DUMP	0.3533	-2.1049	0.1297	0.0473
SWING & REPOS	0.3080	-0.8489	0.4487	0.1415

A simple Weibull cumulative distribution function (c.d.f.) may be defined mathematically as follows:

$$F(t)= \begin{cases} 1 - e^{-(t/\eta)^{\beta}}, & t > 0 \\ 0, & t < 0 \end{cases}$$

Where:

F(t) - probability of a value less than or equal to t occurring,
t - cycle times,
η - characteristic life or scale parameter,
β – slope or shape parameter,
e - exponential.

The parameters eta (η), beta (β), are related to the mean and variance by the following relationship:

$$\text{mean} = \eta\Gamma(1 + 1/\beta)$$
$$\text{variance} = \eta^2[\Gamma(1 + 2/\beta) - \Gamma^2(1 + 1/\beta)]$$

where $\Gamma(\ )$ stands for the gamma function.

Estimations of the Weibull distributions parameters from the time study data was done using an in-house developed program. The program estimates the parameters of a Weibull distribution by the rank regression and maximum likelihood technique. The results showed that the Weibull parameters found using rank regression, fit the data better than those parameters found using maximum likelihood. Table 2 shows the estimated Weibull distribution parameters !or all dragline cycle components.

Table 2 Estimates parameters of dragline cycle times from Weibull distributions

CYCLE TIME COMPONENTS	DISTRIBUTION PARAMETERS		MEAN	STD.DEV
	BETA	ETA	(MIN)	(MIN)
DRAG	3.6024	0.3036	0.2736	0.0844
SWING	4.7535	0.3828	0.3505	0.0841
DUMP	3.7579	0.1420	0.1283	0.0381
SWING & REPOS	3.8273	0.4868	0.4401	0.1285

SLAM 11 MODEL

In order to simulate dragline performance, a stochastic simulation was used to reflect the random variation in duration of all cycle components. The available sample data was hypothesized and fit to a Lognormal probability distribution model. The SLAM II graphical model for this system is shown in Fig.2. SLAM II is an advanced FORTRAN based language that allows simulation models to be built using networks in which are embedded both discrete event and continuous procedures. The entity modelled is the bucket of a Page 757 walking dragline which is used to simulate the production. The entity is assigned three attribute values consisting of:

1) a component of the time cycle,
2) the number of buckets to walk, and
3) the total walk time of the dragline.

The cycle times are generated from Lognormal cumulative distribution functions (inverse transformation method) except for the BUCKWALK (buckets to walk) cycle time which was found to best fit-a Normal distribution. Note that entity is neither created or terminated within the graphical model. This entity will continue to cycle through the network until the simulation is completed. The network model starts at the CREATE node inside the WALK gate. The WALK gate is opened and then the model moves on to an ASSIGN node. At this node attribute 2 is assigned to BUCKWALK. This number indicates how many buckets or cycles the dragline will perform before it walking.

The main simulation now begins at the upper left corner at the ASSIGN node labeled STRT. The attribute 1 is assigned to the drag time and the buckets counter XX(l) is increased by one. At this point, conditional branching is specified from the ASSIGN node where the M-number is one, that is, a maximum of one of the two branches emanating from the ASSIGN node is to be taken.

```
GEN,SZYMANSKI & BORYSUK,DRAGLINE,04/08/88,1,Y,N,Y,N,Y,72;
LIMITS,3,3,90;
RECORD,TNOW,DRALINE,0,P;
TIMST,XX(3),PROD_TPERHR;
EQU/RNORM(419.8060,89.2077),BUCK_WALK/;
EQU/RLOGN(43.8462,21.2641),TOT_WALK_TIME;
EQU/RLOGN(0.2771316,.1105164),DRAG_TIME/;
EQU/RLOGN(0.351786,0.09559936),SWING_TIME/;
EQU/RLOGN(0.1299687,0.05564104),DUMP_TIME/;
EQU/RLOGN(0.4487132,0.145839),SWING_REP_TIME/;
INTLC,XX(1)=0,XX(2)=0; BUCKET COUNTER,PRODUCTION COUNTER
NETWORK;
        RESOURCE/ROCK(1),1;
        GATE/WALK,OPEN,1;
STRT    ASSIGN,ATRIB(1)=DRAG_TIME,
                XX(1)=XX(1)+1,1;  SUMM BUCKETS TO WALK
        ACT,,XX(1).GT.ATRIB(2),ASS2; STOP OPERATING OF THE DRAGLINE
        ACT;
        AWAIT(1),ROCK/1; PROCEED TO DIGGING
        ACT/1,ATRIB(1);  DIGGING OPERATION
        COLCT,ATRIB(1),DRAG_TIME,40,0,.0166;
        ACT,,,ASS1;
        ACT;
        FREE,ROCK/1;      STOP DIGGING
        TERM;
      ;
ASS1    ASSIGN, ATRIB(1)=SWING_TIME;
        ASSIGN,XX(2)=XX(2)+104;  CALCULATE TONNAGE
        ACT/2,ATRIB(1);  SWING
        COLCT,ATRIB(1),SWING_TIME,44,.116,.0166;
        ASSIGN,ATRIB(1)=DUMP_TIME;
        ACT/3,ATRIB(1); DUMPING OPERATION
        COLCT,ATRIB(1),DUMP_TIME,21,0,.0166;
        ASSIGN,ATRIB(1)=SWING_REP_TIME;
        ACT/4,ATRIB(1); SWING AND REPOSITION OPERATION
        COLCT,ATRIB(1), SWING_REP_TIME,44,.116,.0166;
        ASSIGN,XX(3)=XX(2)/TNOW*601;  CALCULATE PRODUCTION RATE
        ACT,,,STRT;
ASS2    ASSIGN,XX(1)=0; INITIALIZE BUCKET TO WALK COUNTER
        AWAIT(2),WALK;
        ASSIGN,ATRIB(3)=TOT_WALK_TIME;
        CLOSE,WALK;
        ACT/5,ATRIB(3); WALK
        COLCT,ATRIB(3),WALK; WALK TIME
        CREATE;
        OPEN,WALK;
        ASSIGN,ATRIB(2)=BUCK_WALK;
        ACTIVITY,,,STRT;
        END;
INIT,0,1440;
MONTR,TRACE,0,2,ATRIB(1),ATRIB(2),ATRIB(3),XX(1),XX(2),XX(3);
FIN;
```

Fig. 2 The statement model for the dragline simulation

If the current number of completed buckets (XX(1)) is equal to the number of buckets to walk (ATRIB(2)), the dragline is branched to the ASSIGN node labeled ASS2. This branch is the walk cycle of the dragline operation. At the ASSIGN node, the buckets to walk counter is re-initialized and attribute 3 is assigned the total walk time. The walk GATE is closed at the AWAIT node and the dragline proceeds to walk. The entity then goes to the COLLECT node where statistics on the walk times are collected. The walk GATE is opened and the entity is looped back to the STRT assign node. If the condition above is not satisfied at the branch emanating from the ASSIGN node, then the entity is logically routed to the AWAIT node where the resource ROCK (mining material) with initial capacity of one is allocated to the bucket. This is the digging cycle of the dragline operation.

The drag operation is represented by the ACTIVITY emanating from the AWAIT node. The drag time is designated activity 1 and has a duration which is specified by the current value of attribute 1. A COLLECT node collects the statistics of the drag cycle times before branching the entities to two branches. The first branch is to the FREE node which releases one unit of the resource rock before terminating this entity from the network. The second branch continues the digging operation by routing the entity to the ASSIGN node labeled ASS1. At this node attribute one is assigned to SWINGTIME, which is the component time for the swing cycle. ACTIVITY 2 represents the swing operation and is performed for the duration specified by attribute 1. Statistics for the swing cycle times are collected at the COLLECT node and then entities are moved to the next ASSIGN node. This node assigns attribute 1 to DUMP_TIME or the time for the dump cycle component. Also, at this node the production value (in tons per hour) is calculated by summing the amount of material moved and dividing it by the elapsed simulation time. The equation XX(2)=XX(2) + 104 calculates the total tonnage of burden moved by adding the previous amount of burden to the equivalent weight of one bucket which is 104 tonnes.

The accumulated tonnage is divided by the elapsed simulation time TNOW to calculate the production rate of the dragline.

Statistics for time persistent variables (production rate) are collected using the TIMST control statement in the model. ACTIVITY 3 then performs the dumping operation for a duration specified by attribute 1 after which statistics are collected at the COLLECT node for this cycle.

The last ASSIGN node in the operation loop assigns attribute 1 to the swing and reposition time of the dragline. This cycle is represented by the ACTIVITY 4 and lasts for the duration of attribute 1. Statistics for the swing and reposition times are collected, then all entities are routed back to the STRT node. The model continues to loop in the manner described above until the alloted simulation time is complete and the program is terminated. The statement model for this simulation is shown in Fig.3.

SUMMARY OF RESULTS

The results of this simulation with PAGE 757 walking dragline (104 tonne bucket), operating continuously over 1440 minute (two shifts) are given in the SLAM II SUMMARY REPORT Figs. 3 and 4.

The first set of statistics "**STATISTICS FOR VARIABLES BASED ON OBSERVATION**", Fig. 3 are those obtained by COLCT nodes. The purpose of this collection was to validate that the stochastic models and parameters used to drive the simulation were truly those desired in the model. Comparison of the sample means and sample standard deviations of dragline drag, swing, dump and swing and reposition times with those expected from their Lognormal parameters (Table 1) show agreement to within the second significant digit. Considering the computational precision employed, this can be considered sufficient for validation of the desired stochastic parameters of the model.

The second statistic in Fig. 3 "**STATISTICS FOR TIME-PERSISTENT VARIABLE**" is that collected in a time integrated sense by tracking change in XX(3), the average production to date. The mean and standard deviation are meaningless here due to the cumulative calculation. The value 1440 gives the total sum of 104 tonne buckets unloaded divided by the total time in hours as the last

SLAM II SUMMARY REPORT

SIMULATION PROJECT DRAGLINE BY SZYMANSKI & BORYSUK

DATE 4/ 8/1988 RUN NUMBER 1 OF 1

CURRENT TIME .1440E+04
STATISTICAL ARRAYS CLEARED AT TIME .0000E+00

STATISTICS FOR VARIABLES BASED ON OBSERVATION

	MEAN VALUE	STANDARD DEVIATION	COEFF. OF VARIATION	MINIMUM VALUE	MAXIMUM VALUE	NO.OF OBS
DRAG_TIME	.275E+00	.112E+00	.407E+00	.645E-01	.938E+00	1119
SWING_TIME	.355E+00	.101E+00	.284E+00	.160E+00	.790E+00	1119
DUMP_TIME	.128E+00	.552E-01	.430E+00	.306E-01	.490E+00	1119
SWING_REP_TIME	.450E+00	.145E+00	.323E+00	.152E+00	.116E+01	1118
WALK	.440E+02	.127E+02	.288E+00	.350E+02	.529E+02	2

STATISTICS FOR TIME-PERSISTENT VARIABLES

	MEAN VALUE	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE	TIME INTERVAL	CURRENT VALUE
PROD_TPERHR	47531.660	10242.650	.0056661.61		1440.000	80.81

FILE STATISTICS

FILE NUMBER	LABEL/TYPE	AVERAGE LENGTH	STANDARD DEVIATION	MAXIMUM LENGTH	CURRENT LENGTH	AVERAGE WAIT TIME
1	AWAIT	.000	.000	1	0	.000
2	AWAIT	.000	.000	0	0	.000
3		.000	.000	0	0	.000
4	CALENDAR	1.001	.037	3	1	.129

REGULAR ACTIVITY STATISTICS

ACTIVITY INDEX/LABEL	AVERAGE UTILIZATION	STANDARD DEVIATION	MAXIMUM UTIL	CURRENT UTIL	ENTITY COUNT
1 DIGGING OPER	.2139	.4101	1	0	1119
2 SWING	.2757	.4469	1	0	1119
3 DUMPING OPER	.0998	.2998	1	0	1119
4 SWING AND RE	.3494	.4768	1	1	1118
5 WALK	.0611	.2395	1	0	2

RESOURCE STATISTICS

RESOURCE NUMBER	RESOURCE LABEL	CURRENT CAPACITY	AVERAGE UTIL	STANDARD DEVIATION	MAXIMUM UTIL	CURRENT UTIL
1	ROCK	1	.21	.410	1	0

RESOURCE NUMBER	RESOURCE LABEL	CURRENT AVAILABLE	AVERAGE AVAILABLE	MINIMUM AVAILABLE	MAXIMUM AVAILABLE
1	ROCK	1	.7861	0	1

GATE STATISTICS

GATE NUMBER	GATE LABEL	CURRENT STATUS	PCT. OF TIME OPEN
1	WALK	OPEN	.9389

Fig. 3 SLAM II summary report (Part 1)

bucket completed. This indicate that the load summer XX(2) would be in order of 17,297 which as we are increamenting by values +104 is still far away from its single precision simulation limit. We conclude that value of 1441.41t/h is a good estimation of productivity of this machine. If we desire more precision in our estimate, we can increase the length of the run or we could do a number of runs at fixed simulation limit. The estimate production rate compares very closely (±5 t/h) with that recorded by mine oeprations.

The statistics given in Fig. 3 deal mainly with waiting lines and utilization of activities, resource and gate. File 1 and 2 the queue of buckets waiting for digging and walking (gate to be closed), indicates that 0.0 minutes of dragline cycle was spent waiting for the digging and for walking. These results are perfectly correct as only one entity (bucket) was in the system. These AWAIT nodes associated with the resource type maintain waiting entitles and are the must in SLAM code. If we add sample mean of dragline utilizations during particular cycle time components, we get a total effective utilization which agrees very well with percentage of time the gate was close (duration of walk).

The resource ROCK (mining overburden) was utilized in 21.39% and it was available for mining in 78.61%.

```
                          **HISTOGRAM NUMBER 1**
                              DRAG_TIME

OBS   RELA   UPPER
FREQ  FREQ   CELL LIM  0         20        40        60        80        100
                       +    +    +    +    +    +    +    +    +    +    +
   0  .000  .000E+00   +                                                  +
   0  .000  .166E-01   +                                                  +
   0  .000  .332E-01   +                                                  +
   0  .000  .498E-01   +                                                  +
   1  .000  .664E-01   +                                                  +
   3  .003  .830E-01   +                                                  +
   6  .005  .996E-01   +                                                  +
  15  .013  .116E+00   +*                                                 +
  35  .031  .133E+00   +**C                                              +
  38  .034  .149E+00   +** C                                             +
  51  .046  .166E+00   +**   C                                           +
  64  .057  .183E+00   +***    C                                         +
  68  .061  .199E+00   +***      C                                       +
  82  .073  .216E+00   +****       C                                     +
  90  .080  .232E+00   +****         C                                   +
  81  .072  .249E+00   +****           C                                 +
  80  .071  .266E+00   +****             C                               +
  64  .057  .282E+00   +***                C                            +
  61  .055  .299E+00   +***                  C                          +
  58  .052  .315E+00   +***                    C                        +
  40  .036  .332E+00   +**                     C                        +
  45  .040  .349E+00   +**                       C                      +
  30  .027  .365E+00   +*                         C                     +
  36  .032  .382E+00   +**                          C                    +
  25  .022  .398E+00   +*                            C                   +
  18  .016  .415E+00   +*                             C                  +
  31  .028  .432E+00   +*                               C                +
  20  .018  .448E+00   +*                                 C              +
   9  .008  .465E+00   +                                   C              +
  11  .010  .481E+00   +                                   C              +
  15  .013  .498E+00   +*                                    C             +
   7  .006  .515E+00   +                                     C             +
   5  .004  .531E+00   +                                      C            +
   5  .004  .548E+00   +                                      C            +
   1  .000  .564E+00   +                                      C            +
   0  .000  .581E+00   +                                      C            +
   5  .004  .598E+00   +                                      C            +
   4  .004  .614E+00   +                                      C            +
   4  .004  .631E+00   +                                       C           +
   2  .002  .647E+00   +                                       C           +
   2  .002  .664E+00   +                                       C           +
   7  .006    INF     +                                       C           +
---                    +    +    +    +    +    +    +    +    +    +    +
***                    0         20        40        60        80        100


          **STATISTICS FOR VARIABLES BASED ON OBSERVATION**

                    MEAN      STANDARD  COEFF. OF  MINIMUM    MAXIMUM   NO.OF
                    VALUE     DEVIATION VARIATION  VALUE        VALUE     OBS

DRAG_TIME         .275E+00  .112E+00  .407E+00  .645E-01  .938E+00  1119
```

FIg. 4 SLAM II summary report (Part 2).